# Recent Results from the Fermilab FOCUS Experiment

FOCUS Beamline and Spectrometer

FOCUS uses a photon beam from bremsstrahlung of a 300 GeV beam of electrons and positrons. The electrons and positrons were produced using an 800 GeV proton beam extracted from the Fermilab Tevatron.

The energy of the photon beam for triggered events range from 50 to 300 GeV with a mean of 180 GeV. The angular spread of the beam is about 1 mrad at the experimental target.

The energies of the incident beam electrons and positrons are measured before bremsstrahlung using 5 planes of silicon microstrip detectors, and again after bremsstrahlung with a shower detector. An electromagnetic calorimeter near the end of the spectrometer measured the energy of uninteracted photons.
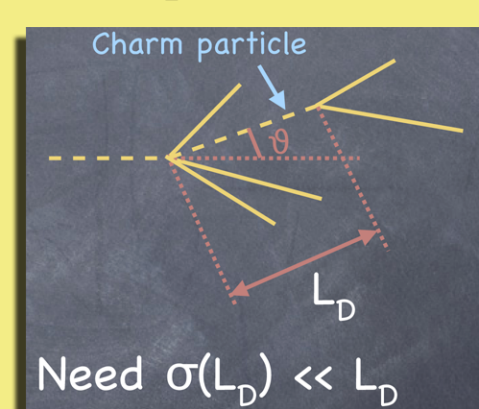
The key to separating clean charm signals from non-charm background in FOCUS is the precision vertex reconstruction using 16 planes of silicon microstrip detectors. The charm decay vertex is required to be detached from the production vertex. To further improve signal-to-background we can also require the decay vertex to be outside of the target.
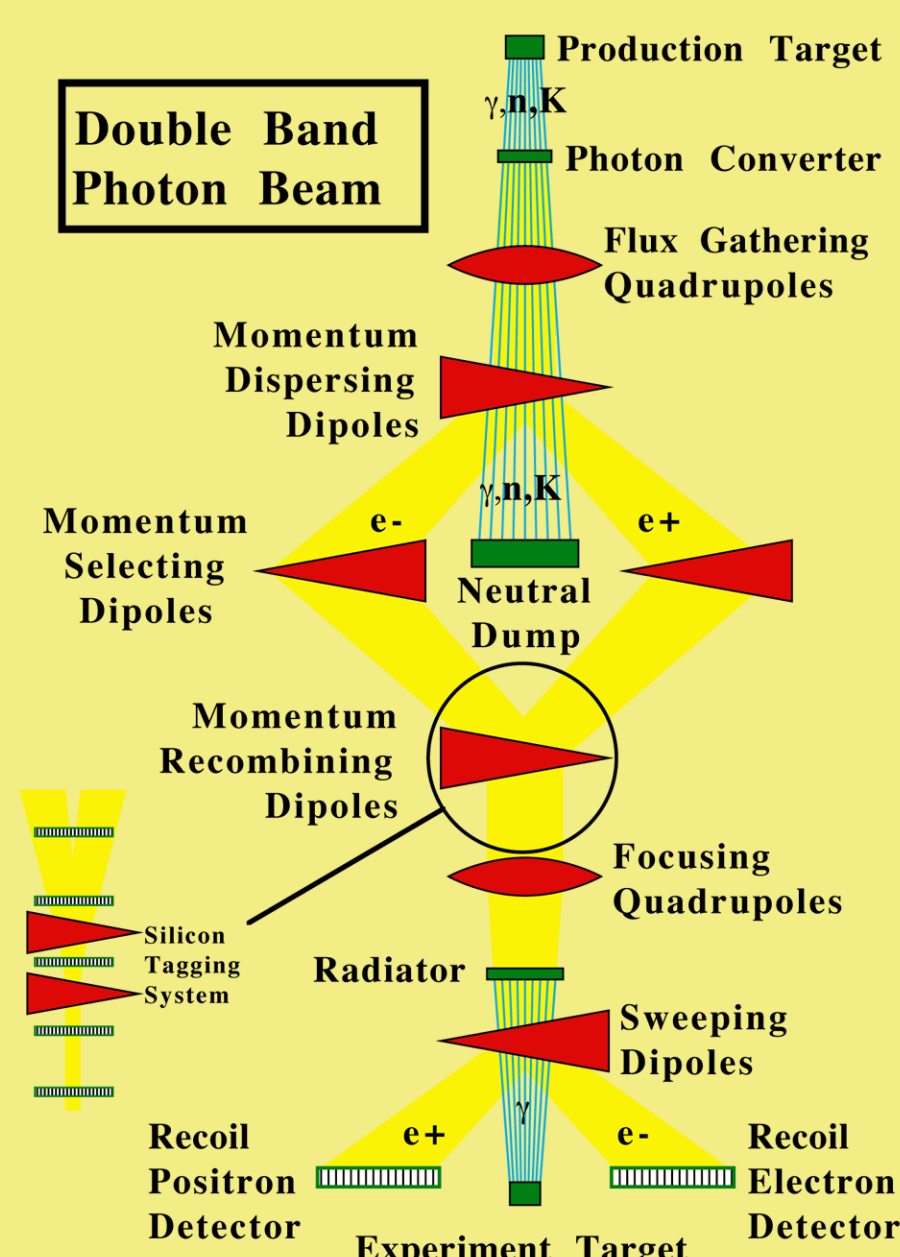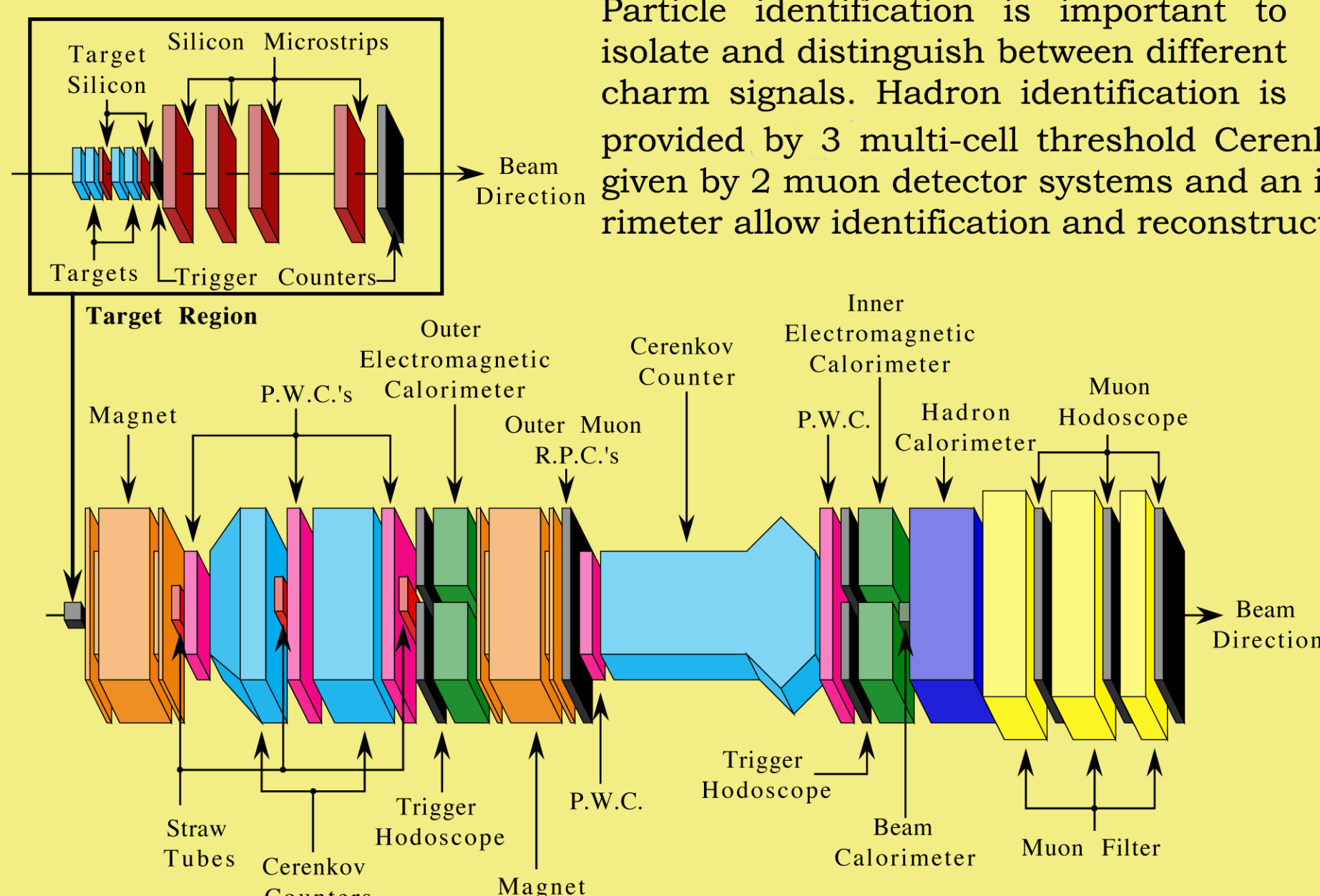
Particle identification is important to isolate and distinguish between different charm signals. Hadron identification is provided by 3 multi-cell threshold Cerenkov counters. Muon identification is given by 2 muon detector systems and an inner and outer electromagnetic calorimeter allow identification and reconstruction of electrons, photons and π^0s.
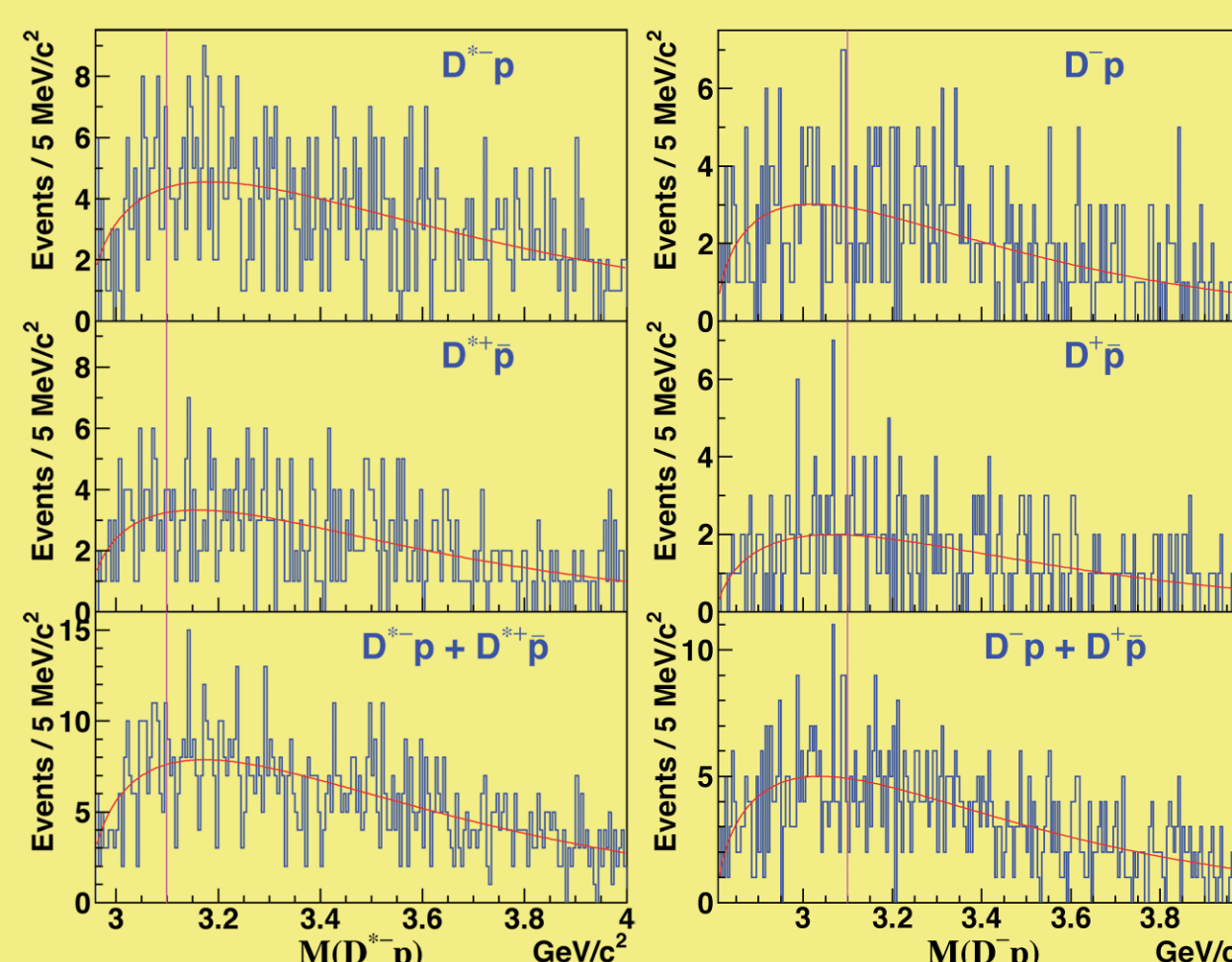
Momentum information for tracks are obtained with 5 wire chambers and two dipole magnets of opposite polarity.

The FOCUS trigger detects when beam photons have hadron producing interactions. So electromagnetic conversions are rejected. This is done with scintillators in the target region, two scintillator hodoscopes downstream of the target and a hadronic calorimeter. 6.5×10^9 events were collected in FOCUS producing 1 million fully reconstructed charm decays.

Double Band Photon Beam

Need $\sigma(L_D) \ll L_D$

Charm Particle Lifetimes

Precise measurements of all the singly charmed particles lifetimes have been made by FOCUS. The latest is for the D_s^+ using $\varphi\pi$ and K^*K decay modes.

Lifetime distribution — **Acceptance correction**

Absolute proper time / Reduced proper time

We use the reduced proper time, $t' = (L - 6\sigma_L)/\beta\gamma c$, to minimize acceptance corrections. Where $L > 6\sigma_L$ is the decay vertex detachment cut used. The reduced proper time distributions for signal and sideband regions are binned in two histograms. The expected number in each time bin in the signal region, and the likelihood used in the fit are:

$$n_i = S\frac{f(t'_i)e^{-t'_i/\tau}}{\sum_i f(t'_i)e^{-t'_i/\tau}} + B\frac{b_i}{\sum_i b_i}$$

$$L = \prod_i \frac{n_i^{s_i}e^{-n_i}}{s_i!} \times \frac{(\alpha B)^{N_b}e^{-\alpha B}}{N_b!}$$

Lifetime and background level, B, are the fit parameters. Results for the lifetimes:

$\varphi\pi^+$: $507.6 \pm 6.5(\text{stat.}) \pm 4.3(\text{syst.})$ fs

$\overline{K}^{*0}K^+$: $506.9 \pm 10.6(\text{stat.}) \pm 8.8(\text{syst.})$ fs

$\tau(D_s^+)$: $507.4 \pm 5.5(\text{stat.}) \pm 5.1(\text{syst.})$ fs

Many systematic studies were done, see hep-ex/0504056 for details.

Compared to other measurements:

Lifetimes (ps) — Spectator Model Value: D^+, D_s^+, Ξ_c^+, D^0, Λ_c^+, Ξ_c^0, Ω_c^0 — FOCUS, PDG'04

Search for a Strongly Decaying Neutral Charmed Pentaquark

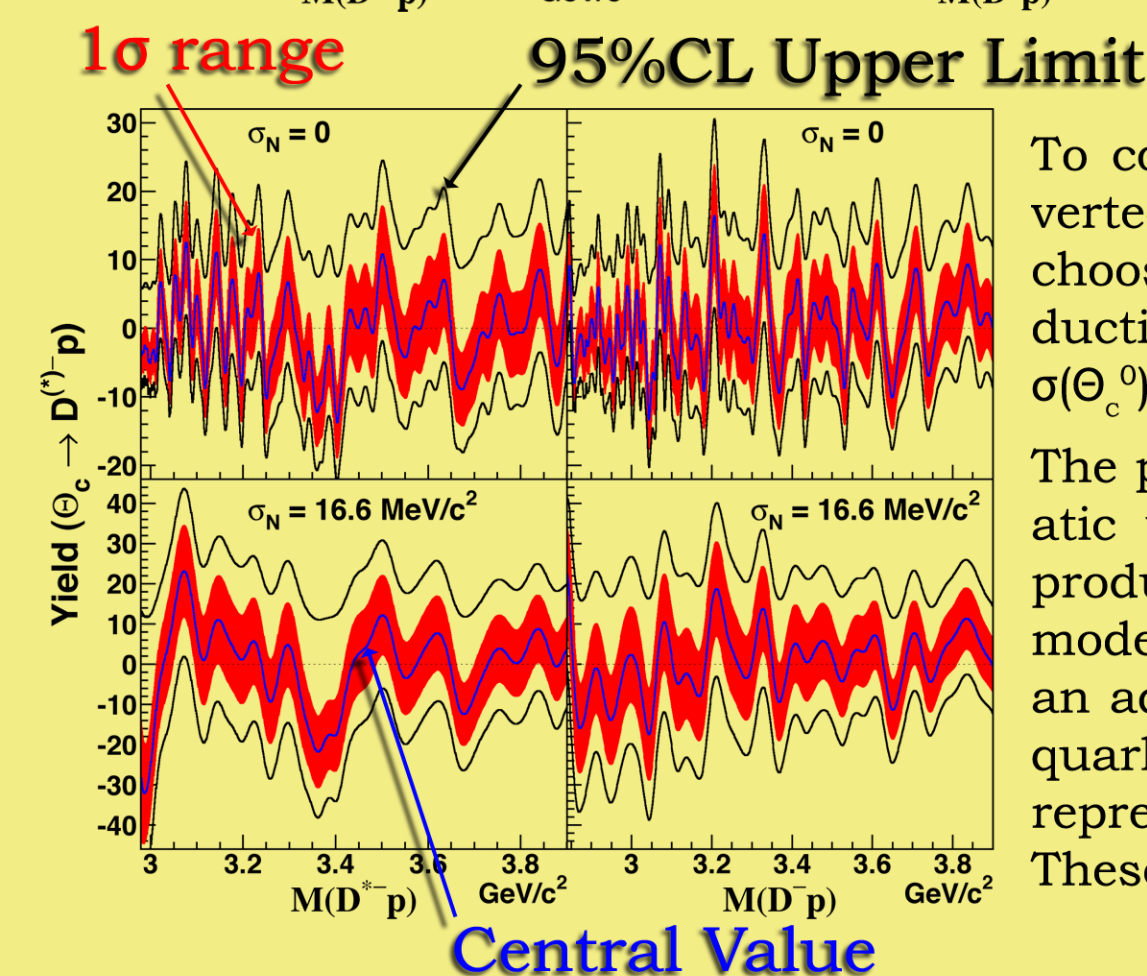Theoretically, the existence of multiquark states, like the $\Theta_c^0(\bar{c}uudd)$, as an observable bound state is inconclusive. The H1 Collaboration reported evidence of a S=0 charmed pentaquark state decaying to $D^{*-}p$ at a mass of $3099\pm3\pm5$ MeV/c^2. We search for the $\Theta_c^0(\bar{c}uudd)$ pentaquark candidate in the $D^{*-}p$ and D^-p decay modes. Since the D^{*+} statistics and data quality of the FOCUS experiment is better than seen in H1 and the production mechanism is similar we should be able to confirm or refute the existence of the purported state.

A decay vertex detachment requirement gives clean samples of the decays $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$, and $D^+ \to K^-\pi^+\pi^+$. The D^{*+} are obtained from $D^{*+} \to D^0\pi_s$. The selection criteria were chosen to maximize $S/\sqrt{B}$. The signal, S, comes from Monte Carlo simulation. The background, B, is obtained from wrong sign data ($D^{(*)-}p$) over the entire mass range (threshold to 4 GeV/c^2). This is an unbiased method of determining the selection criteria.
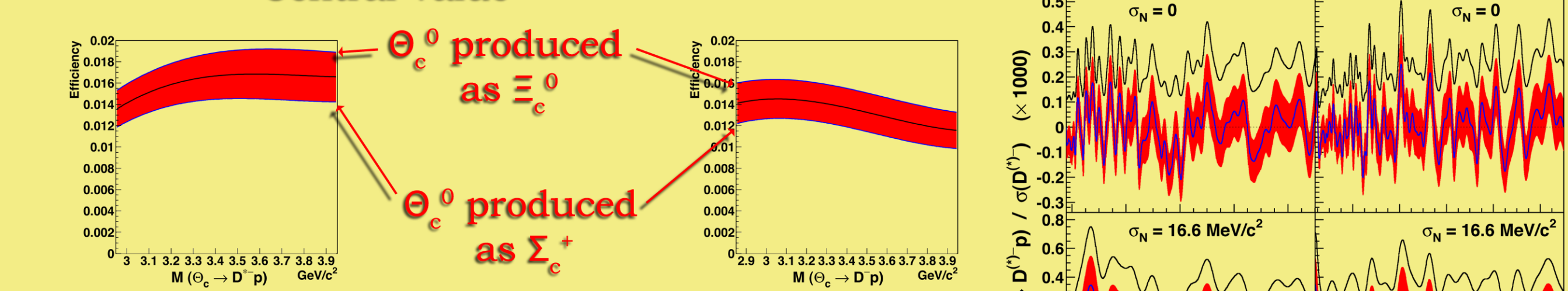
No evidence for a pentaquark at 3.1 GeV/c^2 or at any mass less than 4 GeV/c^2 is observed in the $D^{*-}p$ and D^-p invariant mass plots.

To set a limit on the yield we need information about the width of the state. From the H1 measurement we set the lower limit on the natural width to be 0 and 95%CL upper limit to be 16.6 MeV/c^2. The experimental resolution is added in quadrature with the natural width to get the total width. Limits constructed under these two extreme assumptions will provide the extreme range. The D^-p and D^-p mass plots are fit in 1 MeV/c^2 steps from threshold to 3.9 GeV/c^2. At each step, the mass and width of the Gaussian signal ared fixed while the signal yield and background parameters are fitted.
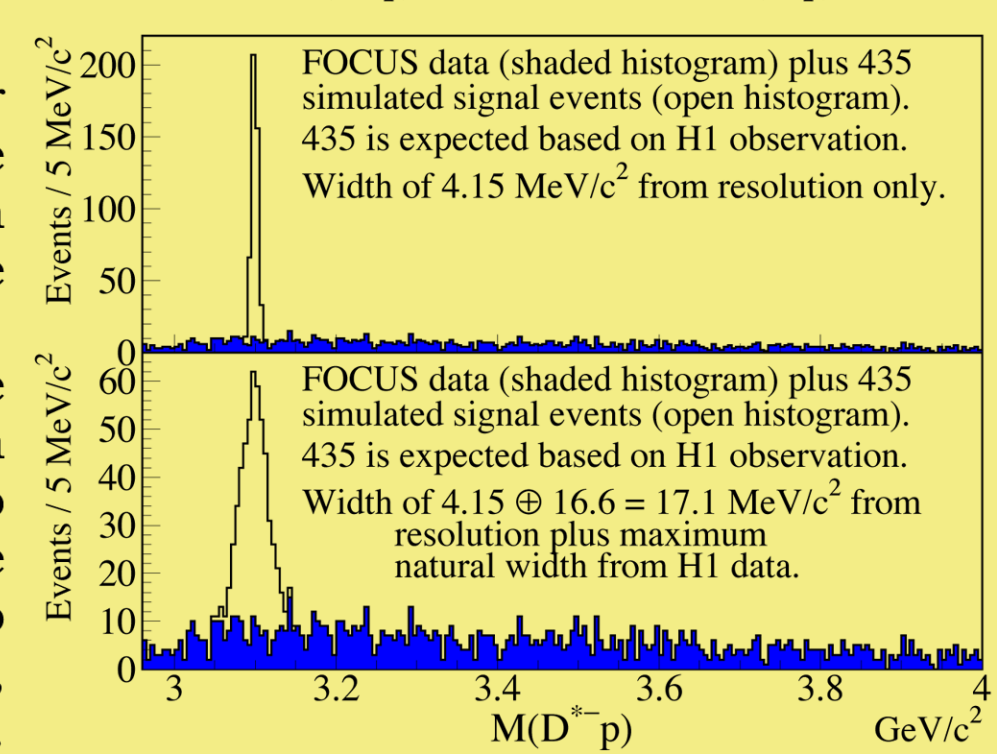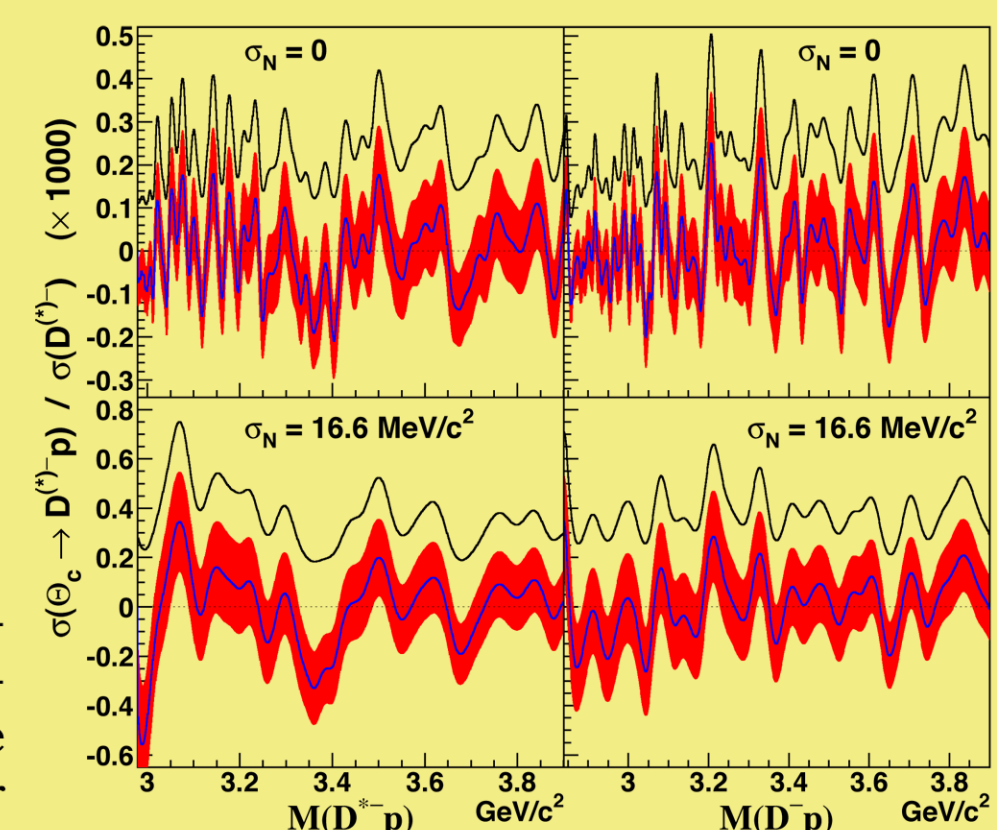
To compare to other experiments, the limits on yield must be converted to limits on production times (unknown) branching ratio. We choose to ratio the Θ_c^0 production cross section to the D meson production cross section from which it is reconstructed. I.e. we determine $\sigma(\Theta_c^0)\times BR(\Theta_c^0 \to D^-p)/\sigma(D^-)$ and $\sigma(\Theta_c^0)\times BR(\Theta_c^0 \to D^+p)/\sigma(D^+)$.

The production characteristics is by far the largest source of systematic uncertainty in this analysis. The acceptance depends on the produced particle momentum. We choose the PYTHIA production model where the pentaquark is represented by a charm baryon with an adjusted mass and zero lifetime. To account for the effects of the quark content on the production, the $\Xi_c^0(csd)$ and $\Sigma_c^+(cud)$ are used to represent the extremes in the production of a charmed pentaquark. These MC simulations are used to get the Θ_c^0 reconstruction efficiency.

1σ range — **95%CL Upper Limit** — **Central Value**

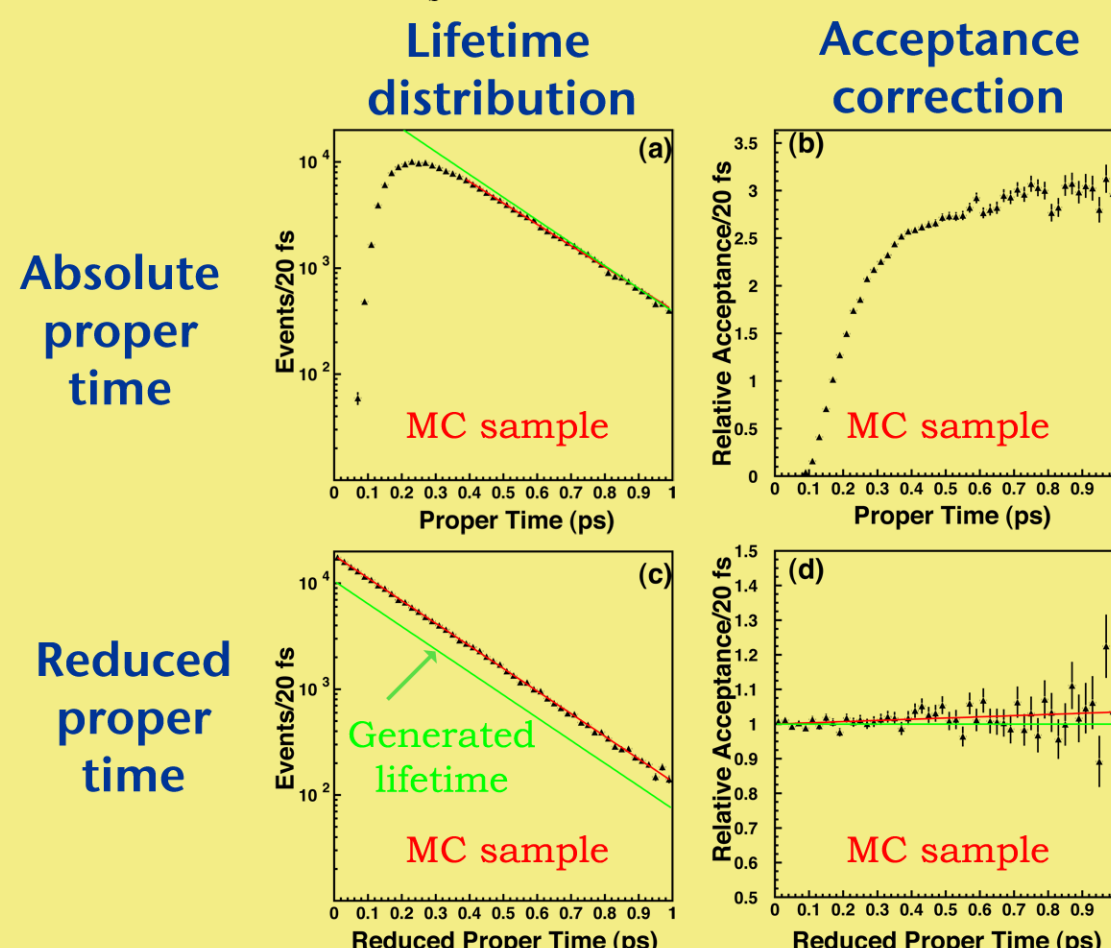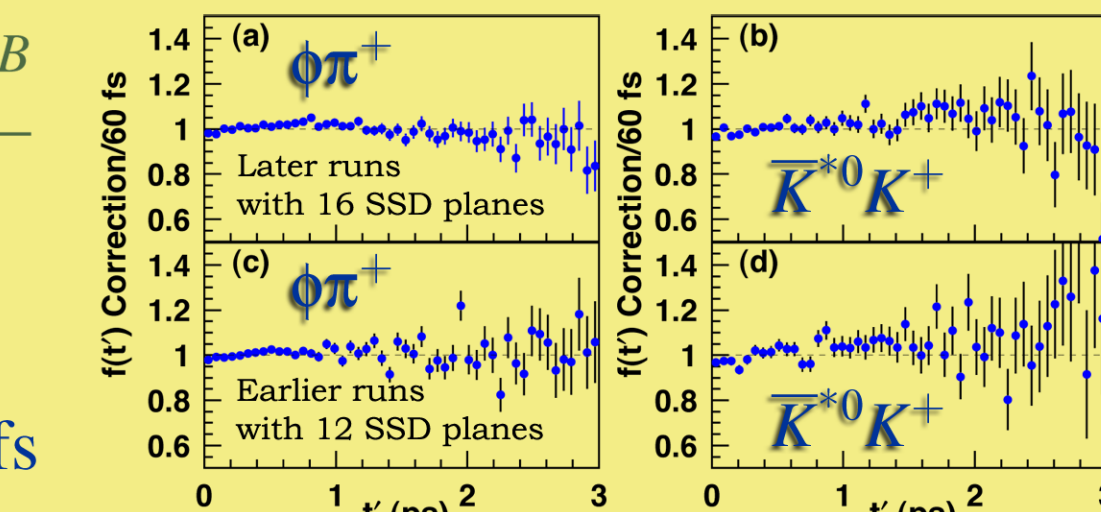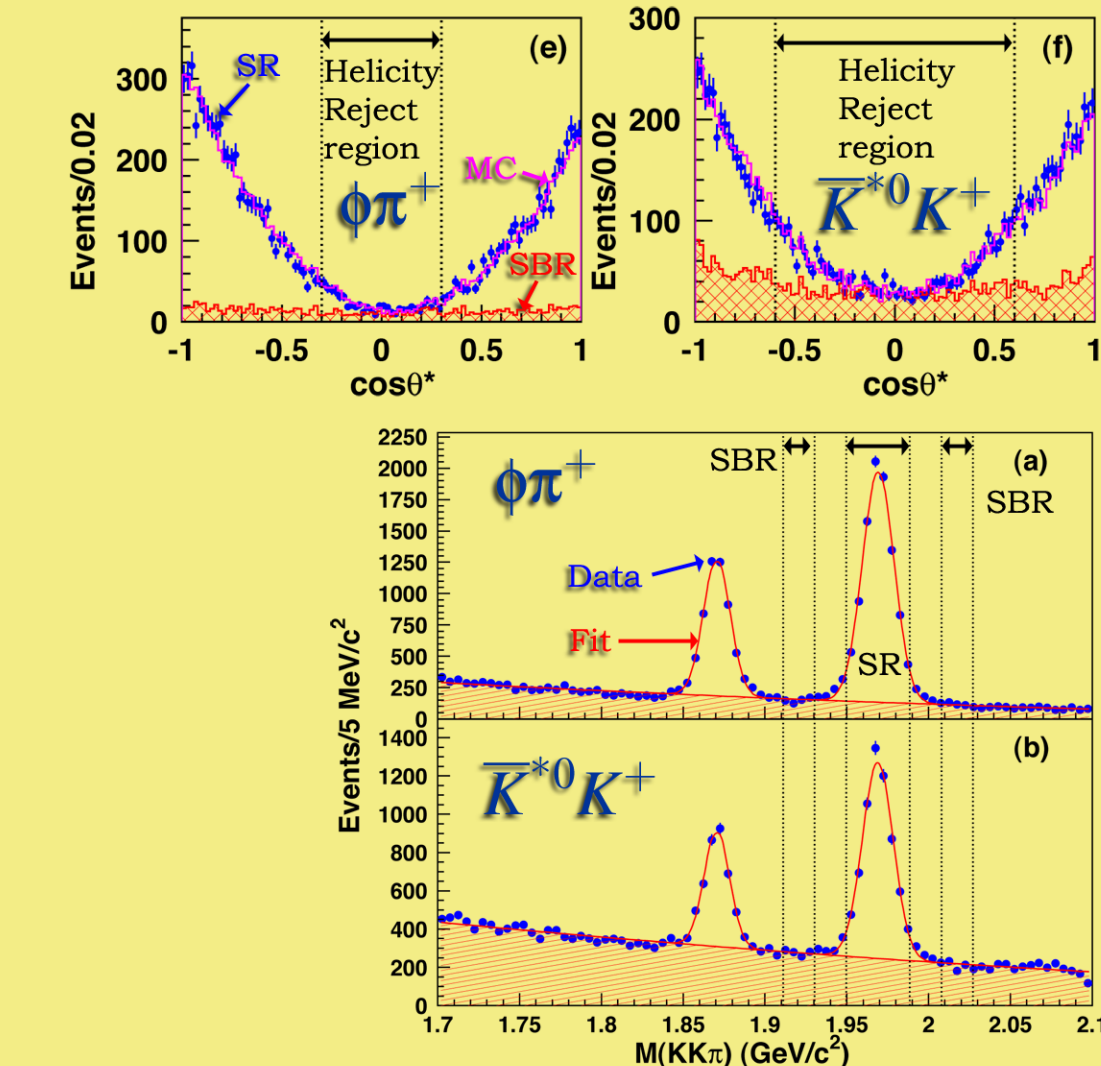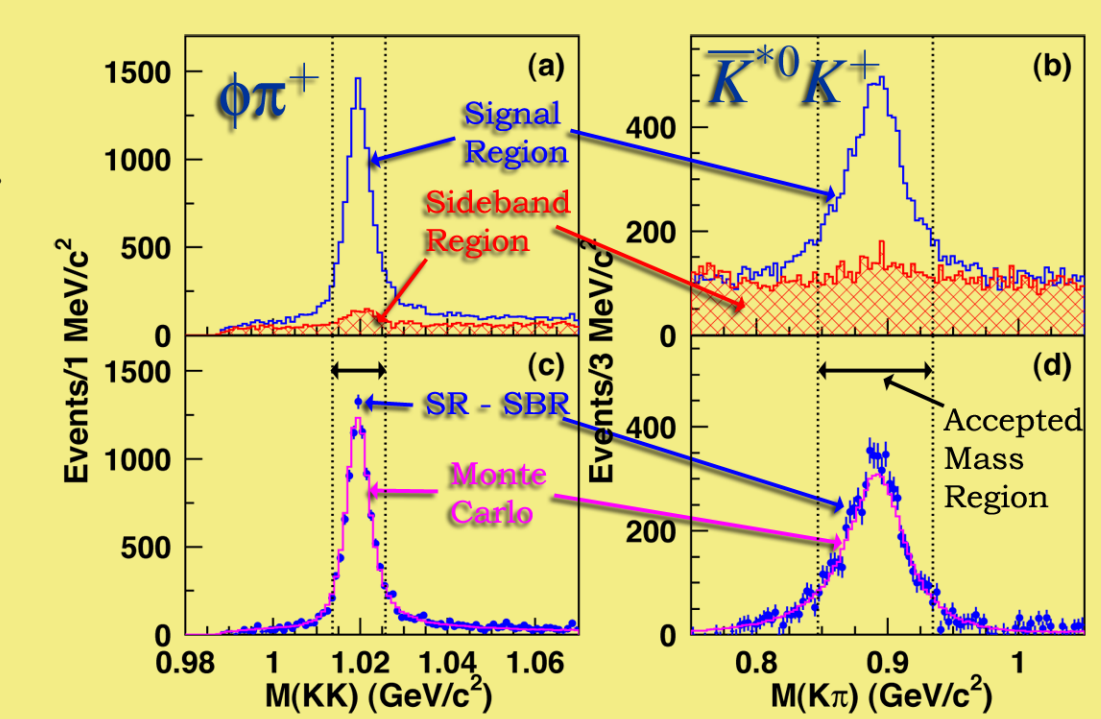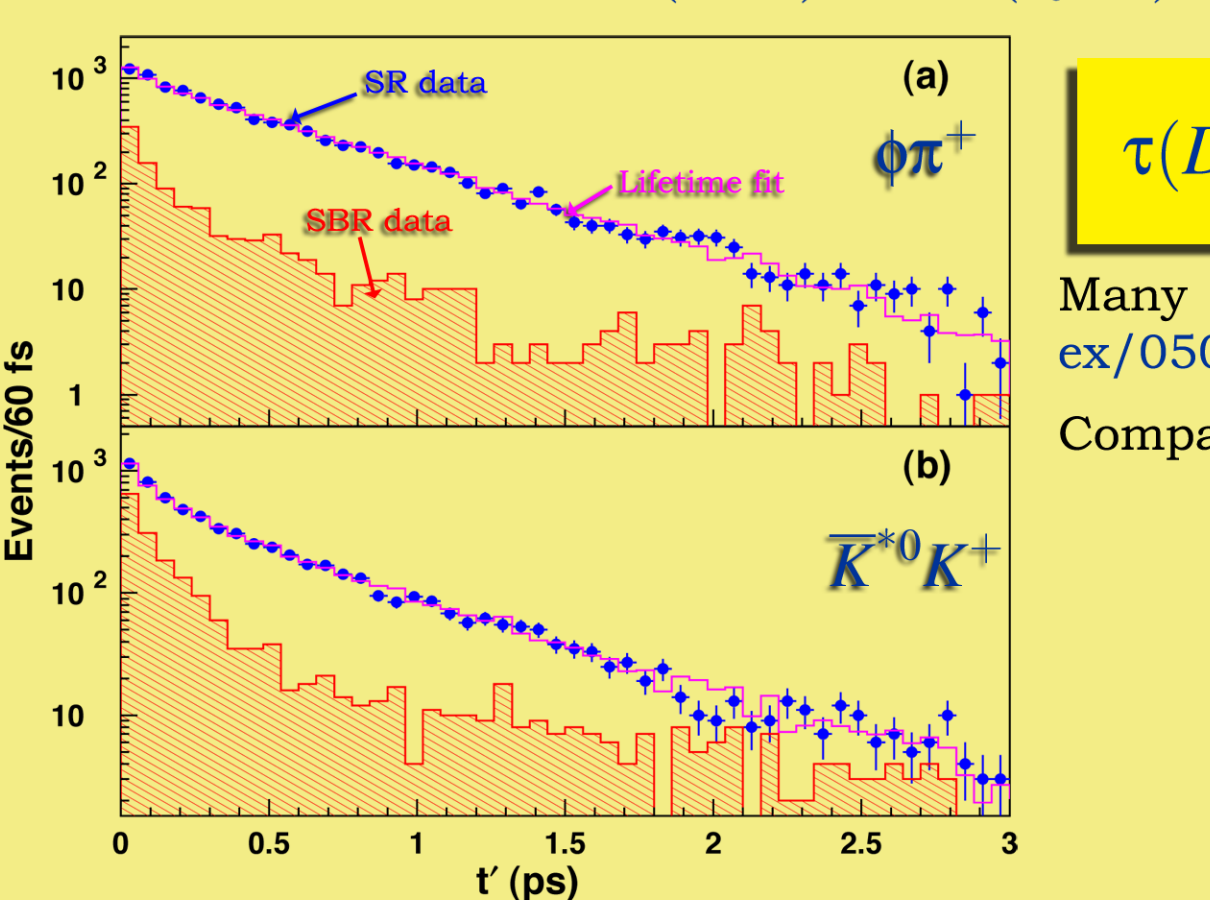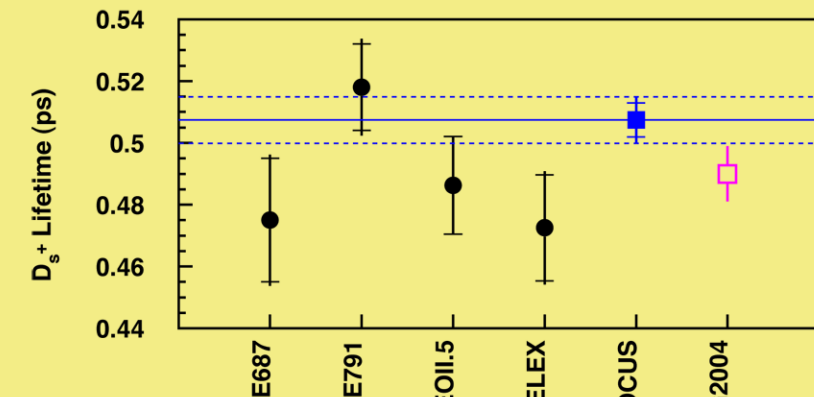Θ_c^0 produced as Ξ_c^0 / Θ_c^0 produced as Σ_c^+

The dominant source of the systematic uncertainty is reflected in the pentaquark reconstruction efficiency. An estimate of this is given by the difference when the Θ_c^0 is produced as Ξ_c^0 or Σ_c^+ compared to the average. The systematic uncertainty is included in the 1σ error and the 95%CL upper limit on $\sigma(\Theta_c^0)\times BR(\Theta_c^0 \to Dp)/\sigma(D)$.

The sample of D^{*-} events is more than 30 times larger as well as cleaner than the sample used by H1 in the paper which reported evidence for the charm pentaquark. While H1 find ~1% of the D^{*-} from Θ_c^0, FOCUS sets an upper limit of 0.075% at 95%CL. The production is similar between the two experiments; virtual (real) photons on protons (nucleons) for H1 (FOCUS). Thus, the H1 result is either a statistical fluctuation or the result of an unusual production mechanism which increases the charm pentaquark to charm cross section by a factor of least 10 in H1 relative to FOCUS. To illustrate this, a study of the difference was performed on the production and acceptance difference in H1 and FOCUS. This was used to scale the $\Theta_c^0(3100)/D^{*+}$ rate reported by H1 to that expected for FOCUS, and to superimpose the Θ_c^0 pentaquark signal FOCUS should have seen. More details of this analysis can be found at hep-ex/0506013.

FOCUS data (shaded histogram) plus 435 simulated signal events (open histogram). 435 is expected based on H1 observation. Width of 4.15 MeV/c^2 from resolution only.

FOCUS data (shaded histogram) plus 435 simulated signal events (open histogram). 435 is expected based on H1 observation. Width of $4.15 \oplus 16.6 = 17.1$ MeV/c^2 from resolution plus maximum natural width from H1 data.

Some Other Recent FOCUS Results

- Search for T Violation in Charm Meson Decays, hep-exp/0506012.
- Study of Λ_c^+ Cabibbo Favored Decays Containing a Λ Baryon in the Final State, hep-ex/0505077.
- Hadronic Mass Spectrum Analysis of $D^+ \to K^-\pi^+\mu^+\upsilon$ Decay and Measurement of the $K^*(892)^0$ Mass and Width, hep-ex/050343.
- Application of Genetic Programming to High Energy Physics Event Selection, hep-ex/0503007.

FOCUS Collaboration Institutions: Univ. of California, Davis; CBPF, Brazil; CINVESTAV, Mexico; Univ. of Colorado, Boulder; Fermi National Accelerator Laboratory, Batavia; LNF and INFN Frascati, Italy; Univ. of Guanajuato, Mexico; Univ. of Illinois, Urbana-Champaign; Indiana Univ., Bloomington; Korea Univ., Korea; Kyungpook National Univ., Korea; INFN and Univ. of Milano, Italy; Univ. of North Carolina, Asheville; Univ. and INFN Pavia, Italy; Pontifcia Univ. Catolica, Brazil; Univ. of Puerto Rico, Mayaguez; Univ. of South Carolina, Columbia; Univ. of Tennessee, Knoxville; Vanderbilt Univ., Nashville; Univ. of Wisconsin, Madison.